

In the Claims:

1. (currently amended) A cardiac pacing system for delivering electrical stimulation to at least three chambers of a heart, said at least three chambers including a left ventricular chamber and a right ventricular chamber, comprising:

a timing circuit to measure at least one time interval, the at least one time interval operatively coupled being used to control delivery of the an electrical stimulation therapy to at least a left ventricular chamber and a right ventricular chamber by a the cardiac pacing system;

a sensing circuit to measure a duration of a QRS complex of a last-to-depolarize ventricular chamber of the heart; and

a control circuit coupled to the timing circuit and the sensing circuit to adjust the length of the at least one time interval based on the measured duration of the QRS complex of the heart.

2. (currently amended) AThe system according to Cclaim 1, wherein the sensing circuit includes a circuit to sense a depolarization in a selected one of the left or right atria of the heart, and wherein the at least one time interval further comprisesincludes an SAV delay initiated upon sensing of the depolarization, and further including comprising:

an output circuit coupled to the timing circuit to:

a) deliver a first ventricular pacing pulse to a first ventricular site disposed in a first ventricular chamber upon expiration of the SAV delay and a second ventricular pacing pulse to a second ventricular site disposed in a second ventricular chamber, wherein said second ventricular pacing pulse is delivered after a temporal interval following delivery of said first ventricular pacing pulse, or

b) upon detecting a ventricular depolarization in said first ventricular chamber prior to expiration of the SAV delay, withholding delivery of the first ventricular pacing pulse and delivering the second ventricular pacing pulse after a temporal interval following detection of said ventricular depolarization, or

c) upon detecting a ventricular depolarization in said second ventricular chamber prior to expiration of the SAV delay, withholding delivery of the second ventricular pacing pulse and delivering the first ventricular pacing pulse after a temporal interval following detection of said ventricular depolarization.

3. (currently amended) ~~The A~~ system according to ~~C~~claim 2, wherein the output circuit includes a circuit to deliver an atrial pacing pulse to the selected one of the left or right atria of the heart upon expiration of an V-A escape interval, and wherein the at least one time interval includes a PAV delay initiated upon delivery of the atrial pacing pulse, and wherein the output circuit ~~includes~~ further comprises a circuit to deliver the first ventricular pacing pulse to the first ventricular site upon expiration of the PAV delay.

4. (currently amended) ~~The A~~ system according to ~~C~~claim 2 ~~or 3~~, wherein ~~the output circuit includes a circuit to deliver a second ventricular pacing pulse to a second ventricular site, and wherein the at least one time temporal interval comprises includes a V-Vbi-ventricular delay elapsing between the first and second ventricular pacing pulses.~~

5. (currently amended) ~~The A~~ system according to ~~C~~claim 4, wherein the first ventricular chambersite is a location within the right ventricle of the heart and the second ventricular chambersite is a location within the left ventricle of the heart.

6. (currently amended) ~~The A~~ system according to ~~C~~claim 4, wherein the first ventricular chambersite is a location within the left ventricle of the heart and the second ventricular chambersite is a location within the right ventricle of the heart.

7. (currently amended) ~~The A~~ system according to ~~C~~claim 4, wherein the output circuit includes a circuit to deliver a pacing pulse to the other one of the left or right atria of the heart.

8. (withdrawn) A multi-site, cardiac pacing system for pacing first and second ventricular sites of a patient's heart comprising:

means for timing out a pacing escape interval;

means for sensing ventricular depolarizations at a first ventricular site and providing a ventricular sense event signal;

means for delivering a first ventricular pacing pulse to the first ventricular site if the pacing escape interval times out before a ventricular sense event signal is provided;

V-V delay timing means for timing a V-V delay from the delivery of the first ventricular pacing pulse or a ventricular sense event;

means for delivering a second ventricular pacing pulse to the second ventricular site at the time-out of the V-V delay; and

means operable upon satisfaction of event criteria for determining the V-V delay that optimizes ventricular cardiac output further comprising:

QRS duration measuring means operable upon delivery of the second pacing pulse for measuring the QRS duration of the evoked depolarization of the heart;

efficacy determining means for determining the efficacy of the delivery of the first and second pacing pulses separated by the V-V delay ascertained from the measured QRS duration;

means for establishing the V-V delay timed out by the V-V delay timing means as the V-V delay found efficacious by the determining means.

9. (withdrawn) The multi-site, cardiac pacing system of Claim 8, wherein the first ventricular site is the right ventricle and the second ventricular site is the left ventricle.

10. (withdrawn) The multi-site, cardiac pacing system of Claim 8, wherein the first ventricular site is the left ventricle and the second ventricular site is the right ventricle.

11. (withdrawn) The multi-site, cardiac pacing system of Claim 8, wherein the efficacy determining means further comprises:

means for changing the V-V delay, whereupon the QRS duration correlated to the V-V delay is measured by the QRS duration measuring means;

means for comparing successively measured QRS durations and determining the shortest QRS duration; and

means for declaring the V-V delay correlated to the shortest QRS duration as the efficacious V-V delay.

12. (withdrawn) The multi-site, cardiac pacing system of Claim 11, wherein the first ventricular site is the right ventricle and the second ventricular site is the left ventricle.

13. (withdrawn) The multi-site, cardiac pacing system of Claim 8, wherein the first ventricular site is the left ventricle and the second ventricular site is the right ventricle.

14. (withdrawn) The multi-site, cardiac pacing system of Claim 8, wherein the means for delivering a first ventricular pacing pulse is operable to deliver the first ventricular pacing pulse upon a ventricular sense event.

15. (withdrawn) The multi-site, cardiac pacing system of Claim 14, wherein the efficacy determining means further comprises:

means for changing the V-V delay, whereupon the QRS duration correlated to the V-V delay is measured by the QRS duration measuring means;

means for comparing successively measured QRS durations and determining the shortest QRS duration; and

means for declaring the V-V delay correlated to the shortest QRS duration as the efficacious V-V delay.

16. (withdrawn) The multi-site, cardiac pacing system of Claim 14, wherein the first ventricular site is the right ventricle and the second ventricular site is the left ventricle.

17. (withdrawn) The multi-site, cardiac pacing system of Claim 14, wherein the first ventricular site is the left ventricle and the second ventricular site is the right ventricle.

18. (withdrawn) The multi-site, cardiac pacing system of Claim 8, wherein the QRS duration measuring means further comprises means for measuring the QRS duration between a pair of sense electrodes located within the patient's body at a distance from the left and right ventricles.

19. (withdrawn) A method of operating a multi-site, cardiac pacing system for pacing first and second ventricular sites of a patient's heart to determine pacing efficacy comprising the steps of:

timing out a pacing escape interval;

sensing ventricular depolarizations at a first ventricular site and providing a ventricular sense event signal;

delivering a first ventricular pacing pulse to the first ventricular site if the pacing escape interval times out before a ventricular sense event signal is provided;

delivering a second ventricular pacing pulse to the second ventricular site at the time-out of the V-V delay; and

determining the V-V delay that optimizes ventricular cardiac output further comprising the steps of :

measuring the QRS duration of the evoked depolarization of the heart upon delivery of the second pacing pulse;

determining the efficacy of the delivery of the first and second pacing pulses separated by the V-V delay from the measured QRS duration;

establishing the V-V delay timed out in the timing step as the V-V delay found efficacious by the determining means.

20. (withdrawn) The multi-site, cardiac pacing method of Claim 19, wherein the first ventricular site is the right ventricle and the second ventricular site is the left ventricle.

21. (withdrawn) The multi-site, cardiac pacing method of Claim 20, wherein the first ventricular site is the left ventricle and the second ventricular site is the right ventricle.

22. (withdrawn) The multi-site, cardiac pacing method of Claim 19, wherein the efficacy determining step further comprises the steps of:

changing the V-V delay, whereupon the QRS duration correlated to the V-V delay is measured by the QRS duration measuring means;

comparing successively measured QRS durations and determining the shortest QRS duration; and

declaring the V-V delay correlated to the shortest QRS duration as the efficacious V-V delay.

23. (withdrawn) The multi-site, cardiac pacing method of Claim 22, wherein the first ventricular site is the right ventricle and the second ventricular site is the left ventricle.

24. (withdrawn) The multi-site, cardiac pacing method of Claim 22, wherein the first ventricular site is the left ventricle and the second ventricular site is the right ventricle.

25. (withdrawn) The multi-site, cardiac pacing method of Claim 19, wherein the means for delivering a first ventricular pacing pulse is operable to deliver the first ventricular pacing pulse upon a ventricular sense event.

26. (withdrawn) The multi-site, cardiac pacing method of Claim 25, wherein the efficacy determining step further comprises the steps of:

changing the V-V delay, whereupon the QRS duration correlated to the V-V delay is measured by the QRS duration measuring means;

comparing successively measured QRS durations and determining the shortest QRS duration; and

declaring the V-V delay correlated to the shortest QRS duration as the efficacious V-V delay.

27. (withdrawn) The multi-site, cardiac pacing method of Claim 25, wherein the first ventricular site is the right ventricle and the second ventricular site is the left ventricle.

28. (withdrawn) The multi-site, cardiac pacing method of Claim 25, wherein the first ventricular site is the left ventricle and the second ventricular site is the right ventricle.

29. (withdrawn) The multi-site, cardiac pacing method of Claim 19, wherein the QRS duration measuring step further comprises measuring the QRS duration between a pair of sense electrodes located within the patient's body at a distance from the left and right ventricles.

30. (withdrawn) In a multi-site, AV sequential, cardiac pacing system wherein ventricular pacing pulses are delivered to the right and left ventricles synchronously within a V-V delay following time-out of an AV delay from a preceding delivered atrial pace pulse or an atrial sense event, in accordance with the steps of:

- (a) timing an AV delay from a preceding delivered atrial pace pulse or an atrial sense event;
- (b) detecting a ventricular depolarization in one of the right and left ventricle within the AV delay and, in response, terminating the AV delay and providing a ventricular sense event;
- (c) delivering a ventricular pace pulse to selected one of the right and left ventricle upon the time-out of the AV delay;

(d) timing the V-V delay from a ventricular sense event occurring prior to the time-out of the AV delay or from a ventricular pace pulse delivered at the end of the AV delay; and

(e) delivering a ventricular pace pulse to the other of the right and left ventricle upon the time-out of the V-V delay;

a method of periodically optimizing cardiac output achieved by the synchronous pacing of the right and left ventricles comprising the steps of:

(f) measuring the QRS duration of the evoked depolarization of the other of the right and left ventricle paced at the time-out of the V-V delay following step (e);

(g) adjusting the V-V delay;

(h) repeating steps (a) through (g) to derive a set of measured QRS duration values correlated with a set of V-V delays;

(i) determining the shortest QRS duration; and

(j) employing the V-V delay correlated with the shortest QRS duration in step (d) until steps (f) through (i) are repeated.

31. (withdrawn) The multi-site, AV sequential cardiac pacing method of Claim 30, further comprising a method of periodically optimizing cardiac output achieved by the synchronous pacing of atria and the right and left ventricles comprising the steps of:

(k) measuring the QRS duration of the evoked depolarization of the other of the right and left ventricle paced at the time-out of the V-V delay following step (e);

(l) adjusting the AV delay;

(m) repeating steps (a) through (e), (k) and (l) to derive a set of measured QRS duration values correlated with a set of AV delays;

(n) determining the shortest QRS duration; and

(o) employing the AV delay correlated with the shortest QRS duration in steps (a) through (e) until steps (k) through (o) are repeated.

32. (withdrawn) The multi-site, AV sequential cardiac pacing method of Claim 31, wherein the AV delay is a sensed AV delay that is timed out in step (a) following an atrial sense event.



33. (withdrawn) The multi-site, AV sequential cardiac pacing method of Claim 31, wherein the AV delay is a paced AV delay that is timed out in step (a) following delivery of an atrial pace pulse.

34. (withdrawn) The multi-site, AV sequential cardiac pacing method of Claim 30, wherein a first ventricular pacing pulse is delivered in step (c) upon a ventricular sense event.

35. (withdrawn) The multi-site, cardiac pacing method of Claim 30, wherein the QRS duration measuring step (f) further comprises measuring the QRS duration between a pair of sense electrodes located within the patient's body at a distance from the left and right ventricles.

36. (withdrawn) In a multi-site, AV sequential, cardiac pacing system wherein ventricular pacing pulses are delivered to the right and left ventricles synchronously within a V-V delay following time-out of an AV delay from a preceding delivered atrial pace pulse or an atrial sense event, comprising:

(a) means for timing an AV delay from a preceding delivered atrial pace pulse or an atrial sense event;

(b) means for detecting a ventricular depolarization in one of the right and left ventricle within the AV delay and, in response, terminating the AV delay and providing a ventricular sense event;

(c) means for delivering a ventricular pace pulse to selected one of the right and left ventricle upon the time-out of the AV delay;

(d) means for timing the V-V delay from a ventricular sense event occurring prior to the time-out of the AV delay or from a ventricular pace pulse delivered at the end of the AV delay; and

(e) means for delivering a ventricular pace pulse to the other of the right and left ventricle upon the time-out of the V-V delay;

a system that periodically optimizes cardiac output achieved by the synchronous pacing of the right and left ventricles comprising the steps of:

- (f) means for measuring the QRS duration of the evoked depolarization of the other of the right and left ventricle paced at the time-out of the V-V delay;
- (g) means for adjusting the V-V delay;
- (h) means for repeating the operations of means (a) through (g) to derive a set of measured QRS duration values correlated with a set of V-V delays;
- (i) means for determining the shortest QRS duration; and
- (j) means for employing the V-V delay correlated with the shortest QRS duration in means (d) until the system is enabled to again optimize cardiac output.

37. (withdrawn) The multi-site, cardiac pacing method of Claim 36, wherein the QRS duration measuring means further comprises means for measuring the QRS duration between a pair of sense electrodes located within the patient's body at a distance from the left and right ventricles.

38. (withdrawn) The multi-site, AV sequential cardiac pacing system of Claim 36, wherein the system that periodically optimizes cardiac output achieved by the synchronous pacing of atria and the right and left ventricles further comprises:

- (k) means for adjusting the AV delay;
- (l) means for repeating the operations of means (a) through (g) to derive a set of measured QRS duration values correlated with a set of AV delays;
- (m) means for determining the shortest QRS duration; and
- (n) means for employing the AV delay correlated with the shortest QRS duration in means (d) until the system is enabled to again optimize cardiac output.

39. (withdrawn) The multi-site, AV sequential cardiac pacing system of Claim 38, wherein the AV delay is a sensed AV delay that is timed out in means (a) following an atrial sense event.

40. (withdrawn) The multi-site, AV sequential cardiac pacing method of Claim 38, where in the AV delay is a paced AV delay that is timed out in step (a) following delivery of an atrial pace pulse.

41. (withdrawn) The multi-site, AV sequential cardiac pacing system of Claim 36, wherein a first ventricular pacing pulse is delivered upon a ventricular sense event.

42. (currently amended) A method for ~~use in a cardiac pacing system for~~ optimizing delivery of therapeutic electrical stimulation to at least three chambers of a heart, said at least three chambers including a left ventricular chamber and a right ventricular chamber, comprising the methods steps of:

(a) ~~timing measuring~~ at least one time interval between at least two of the following cardiac events:

an atrial depolarization event, an atrial pace event, a left ventricular depolarization event, a left ventricular pace event, a right ventricular depolarization event, a right ventricular pace event;

obtaining a presently enabled, programmable value of a one of: a sensed A-V interval, a paced A-V interval, a V-A escape interval;

(b) delivering a therapeutic electrical stimulation to a first atrial chamber followed by a first ventricular chamber and subsequently location in to a second ventricular chamber of the heart at a predetermined times relative to either the at least one time interval or the programmable value;

(c) for a given cardiac cycle, measuring a duration of a QRS complex duration of a last-to-depolarize ventricular chamber of the heart;

storing the measured QRS complex duration; and

(d) adjusting at the temporal length of the at least one time interval based on the measured duration of the QRS complex of the last-to-depolarize ventricular chamber of the heart.

43. (currently amended) ~~The~~ A method according to Claim 42, and further comprising the ~~step method~~ of:

sensing a depolarization in a selected one of the left atria or a right atria of the heart;

and wherein the at least one time interval includes an SAV delay initiated from the occurrence of the sensed depolarization of the left atria or the right atria, and further comprising ~~wherein the~~

delivering therapeutic cardiac pacing electrical stimulation is delivered to the first ventricular chamber location in the heart upon expiration of the SAV delay.

44. (currently amended) ~~The~~A method according to ~~C~~claim 43, wherein the first ventricular chamber comprises ~~location is a location within a selected one of the left or right ventricles.~~

45. (currently amended) ~~The~~A method according to ~~C~~claim 44, and further comprising ~~the methods of~~ wherein for a subsequent cardiac cycle,

delivering atrial electrical stimulation to the selected one of the left or right atria of the heart if the an atrial depolarization is not sensed within a predetermined period time, delivering an atrial pacing stimulus to an atrial chamber following expiration of a V-A escape interval;

and wherein the at least one time interval includes an PAV delay commenced relative to the delivery of the atrial electrical stimulation, and wherein the delivery of therapeutic electrical stimulation to the first location in the heart occurs following expiration of a paced A-V interval ~~the PAV delay.~~

46. (currently amended) ~~The~~A method according to ~~C~~claim 42, wherein the step of delivering a therapeutic electrical stimulation to a first atrial chamber followed by a first ventricular chamber and subsequently to a second ventricular comprises the first location is within the right or the left ventricle, and further comprising the method of delivering therapeutic electrical stimulation to the second ventricular chamber to a location within the other one of the left or right ventricles following expiration of the a V-V delay ~~at least one time interval.~~

47. (currently amended) ~~The~~A method according to ~~claim~~ 44, and further comprising the ~~method step~~ of delivering electrical stimulation to the other one of the left or right ventricles following expiration of a V-V delay, where in the V-V delay is one of the at least one time intervals.

48. (new) A computer readable medium for storing instructions for performing a method, comprising:

instructions for measuring at least one time interval, the at least one time interval being used to control delivery of an electrical stimulation therapy to at least a left ventricular chamber and a right ventricular chamber by a cardiac pacing system;

instructions for measuring a duration of a QRS complex of a last-to-depolarize ventricular chamber of a heart; and

instructions for controlling a timing circuit and a sensing circuit to adjust the length of the at least one time interval based on the measured duration of the QRS complex of the last-to-depolarize ventricular chamber of the heart.

49. (new) A computer readable medium according to claim 48, further comprising:

instructions to deliver a first ventricular pacing pulse to a first ventricular site disposed in a first ventricular chamber upon expiration of an SAV delay and a second ventricular pacing pulse to a second ventricular site disposed in a second ventricular chamber, wherein said second ventricular pacing pulse is delivered after a temporal interval following delivery of said first ventricular pacing pulse;

instructions to, upon detecting a ventricular depolarization in said first ventricular chamber prior to expiration of the SAV delay, withhold delivery of the first ventricular pacing pulse and deliver the second ventricular pacing pulse after a temporal interval following detection of said ventricular depolarization; and

instructions to, upon detecting a ventricular depolarization in said second ventricular chamber prior to expiration of the SAV delay, withhold delivery of the second ventricular pacing pulse and deliver the first ventricular pacing pulse after a temporal interval following detection of said ventricular depolarization.

50. (new) A system for providing cardiac pacing therapy to at least three chambers of a heart, comprising:

means for measuring at least one time interval, the at least one time interval being used to control delivery of an electrical stimulation therapy to at least a left ventricular chamber or a right ventricular chamber by a cardiac pacing system;

means for measuring a duration of a QRS complex of a last-to-depolarize ventricular chamber of a heart; and

means for controlling a timing circuit and a sensing circuit to adjust the length of the at least one time interval based on the measured duration of the QRS complex of the last-to-depolarize ventricular chamber of the heart.

51. (new) A system according to claim 50, further comprising:

means for delivering a first ventricular pacing pulse to a first ventricular site disposed in a first ventricular chamber upon expiration of an SAV delay and a second ventricular pacing pulse to a second ventricular site disposed in a second ventricular chamber, wherein said second ventricular pacing pulse is delivered after a temporal interval following delivery of said first ventricular pacing pulse;

means for, upon detecting a ventricular depolarization in said first ventricular chamber prior to expiration of the SAV delay, withholding delivery of the first ventricular pacing pulse and delivering the second ventricular pacing pulse after a temporal interval following detection of said ventricular depolarization; and

means for, upon detecting a ventricular depolarization in said second ventricular chamber prior to expiration of the SAV delay, withholding delivery of the second ventricular pacing pulse and delivering the first ventricular pacing pulse after a temporal interval following detection of said ventricular depolarization.